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Technical Lesson 63

SHORT WAVE TRANSMITTERS

Although short wave transmitters are very simple in design, requiring but few parts and are often operated on very low power as compared with long wave transmitters, it should not be thought that these small transmitters are inefficient in long distance communication. Operators of numerous short wave sets have successfully carried on transmissions over very long distances, often exceeding 3000 miles.

Before continuing with our discussion of the transmitter circuits let us relate about the theory which is generally accepted in scientific circles concerning the propagation of short waves through space. The theory we refer to is known as the "Heaviside" theory, which in brief, assumes that very short waves do not follow the curvature of the earth, as the longer waves are supposed to do, but the short waves are reflected by some medium in the upper atmosphere.

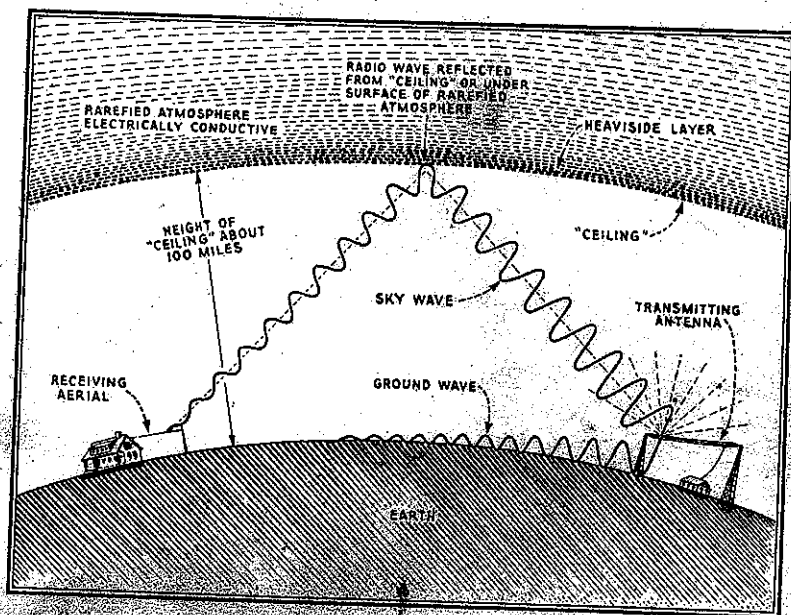


Figure 1

Theories Advanced Relating to the Propagation of Radio Waves Through Space.

Experience proves that a radio wave travels greater distances just after sun-down and at night than during the daylight and also that waves emitted by a particular station often change their apparent direction of travel and are heard in receiving sets with greater volume in certain localities than others. In certain areas reception from particular stations is quite impossible as you would appreciate if you have had experience in operating a receiver in one of these areas, which are known as "dead-spots". However, in any location, even in those which are favorable for radio reception, there are times when

a certain amount of periodic diminishing or fading of the signal energy is experienced, which among other peculiarities exhibited by a radio wave, is largely accounted for by the theories of propagation advanced by the late English scientist, Oliver Heaviside. He suggested that a strata of rarified air exists about one hundred miles above the earth's surface, which region is electrically conductive because of its ionized condition. The height of the ceiling of this upper strata rapidly changes as the sun's rays act to vary the density of the ionized condition. A low ceiling or ionized atmosphere tends to absorb the energy in a radio wave and it may disappear entirely after travelling a hundred miles, or even less, from the transmitting antenna. The radio wave is thought to be composed of two components, one being a ground wave which travels along the curvature of the earth, and the second a sky wave, which is projected toward the upper ionized strata or "Heaviside Layer". The sky wave is then reflected from the under surface of the ionized layer, the ceiling as it is called, at an angle toward the earth, this reflection being compared to light from a mirror. Just how this effect upon radio transmissions is thought to be brought about may be visualized as shown by our sketches in Figures 1 and 2. There it can be seen how the wave of a certain radio signal could be absorbed practically a short distance from the transmitting antenna, yet the reflected sky wave might reach the earth at certain locations many hundreds of miles distant, thus accounting for long distance reception.

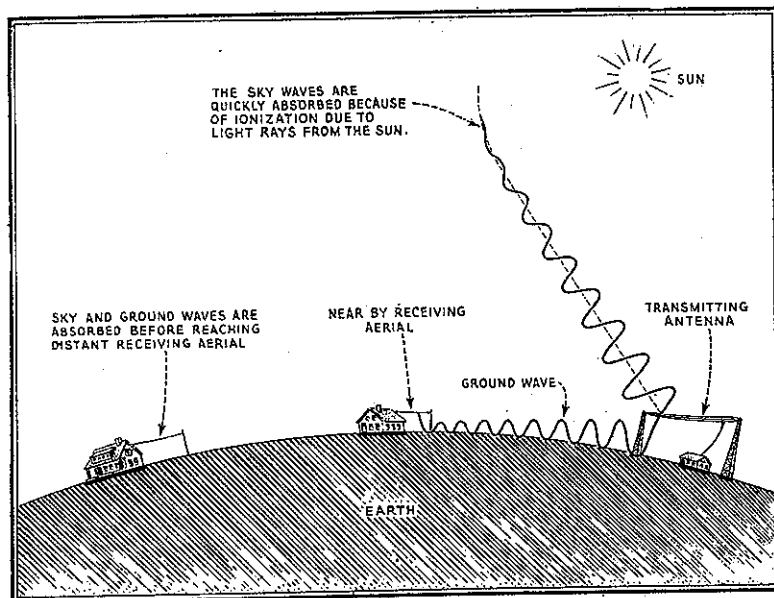


Figure 2

The reflection of sky waves results in what is termed "The skipped distance effect", and as we have just said a signal may be inaudible a few hundred miles from the transmitter and very strong several thousands of miles away. This phenomenon varies according to the wavelengths used, the time of day, and the location of the transmitter. It becomes more noticeable at the higher frequencies, or lower waves, and is also dependent somewhat upon the seasons and the power supplied to the transmitter.

The theories relating to the projection of an electromagnetic wave through space are intensely interesting, but cannot be dealt with at length in our lesson, because we are more concerned just now in the fundamentals of short wave transmitting apparatus.

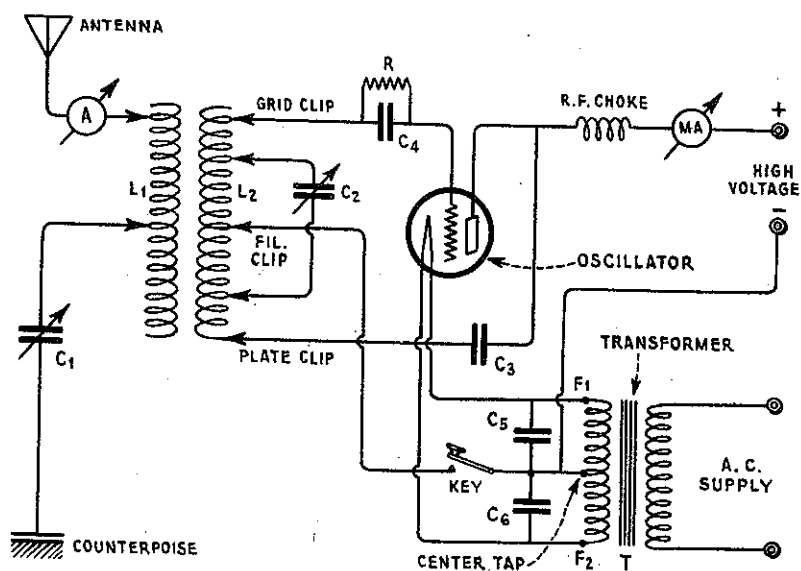


Figure 3

The various elements embodied in the two circuits can be easily identified by the following legend:

- L1 Antenna Inductance
L2 Oscillatory Circuit (Closed Circuit) Inductance
A Thermo-Couple Type Radiation Ammeter
C1 Antenna Series Condenser
C2 Variable Tuning Condenser in Shunt to L2

C3 Plate Blocking Condenser
 C4 Grid Condenser
 C5 Filament By-pass Condenser
 C6 Filament By-pass Condenser
 MA D.C. Milliammeter
 T Step-down Filament Transformer

The shunt feed Hartley circuit in Figure 3 depends for its operation upon the voltage drop obtained from the inductances between the grid clip and filament clip when current flows. This voltage used to excite the grid is responsible for the persistent generation of continuous oscillations. Alternating current provides a very convenient means for supplying the filament, obtained from the use of a step-down transformer. A rheostat (not shown) is usually inserted in the primary or input side of the transformer in order to regulate the terminal e.m.f. of the filament. This should be adjusted to within certain limits according to the characteristics of the tube used. Many installations use direct current for filament supply obtained from a storage battery. Suppose that battery supply is used instead of the a-c. in the shunt feed circuit shown in Figure 3, then it would be necessary to slightly modify the filament connections as follows: The lead marked F1 would be run to the positive post of the battery, lead F2 to the negative post, and the center tap lead to F1, i.e., to the positive side of the filament supply.

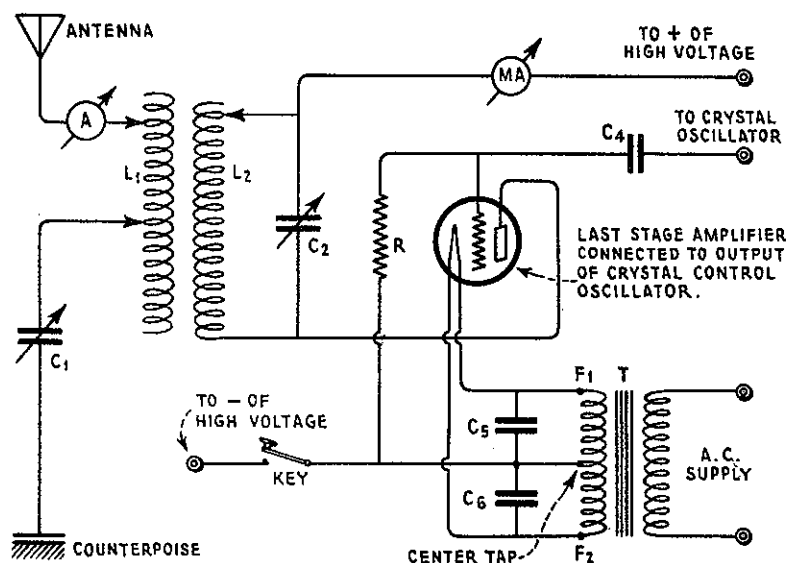


Figure 4

One method for keying short wave transmitters of the above type is to insert the sending key in the center-tap lead to the transformer secondary as indicated in the diagram. By placing a 1.0 mfd. condenser across the key contacts, arcing at the points will be practically absorbed, or if a condenser alone proves insufficient, a resistor of approximately 10,000 ohms should be put in series with the condenser. Other methods of keying commonly used are either to break the grid circuit, or to affect a change in the operating grid bias from a low value to a high value.

For short waves all of the apparatus should be designed expressly for the purpose to which it is put. Also, special attention should be given to the mounting of the co-related parts with their circuit connections. The photographs in Figures 5, 6, 7 and 8 show different views of the same transmitter designed for short waves. The mechanical relation of the parts and special features in design are clearly indicated in the photographs which are reproduced by the courtesy of QST. In most types of sets, the transmitting inductances are constructed of either copper tubing or flat copper ribbon wire wound edgewise or flatwise supported in certain cases by crystal glass spacers or some material possessing the highest insulating properties, or we might say a material having a high dielectric strength.

The short wave spectrum is separated into channels, known as the 5 - 20 - 40 - 80 and 150 meter wave bands. The number of turns used and the size of the inductance correspond to the capacity which is shunted across them for the purpose of wavelength adjustment.

Condensers. In general, short wave circuits are supplied with two variable condensers, one being usually shunted across the secondary inductance for obtaining the proper frequency, and the other shunted between the plate and the oscillatory circuit to control the feed-back voltage.

The transmitting condensers are ruggedly constructed as can be seen in the photographs. Since reception of short wave signals is very critical the condensers used in the transmitter are carefully designed so that they will be unaffected by atmospheric conditions which might tend to alter their capacity to a very slight degree, but sufficient possibly to vary the circuit constants and the frequency. So when once a transmitter has been tuned to the assigned frequency it should not be permitted to "swing off" this frequency, if consistent communication is to be maintained.

These condensers have widely spaced plates which give them a very high break down potential. Remember that high voltages are applied to such condensers in many cases and that air is the dielectric medium. Break down potential (or break down voltage) varies for different condensers and run as high as 10,000 volts in some types and may still reach higher values. Thus, we learn that transmitting condensers are rated both according to their capacity and break down potential. To obtain the desired electrical and mechanical features the plates are accurately spaced and made of heavy brass or aluminum. Also to reduce losses due to brush discharge all sharp edges and corners are smoothed or rounded off. By careful design of frame construction, stator plate and rotor plate assembly, creepage losses are kept to a minimum.

Short Wave Antennas. Antennas used for short wave transmission should be located entirely out-of-doors, if surrounding conditions permit, or if the lead-in wire enters the building, the wire should be located in an unobstructed area, free from trees, metallic structures, or other energy-absorbing bodies. A counterpoise is often required, although not always, and its correct length and height from the ground must be found by experiment. In general, the antenna and counterpoise should be of the same length, this length representing the total amount of wire used from one extreme and to the other, including the lead-in. To explain this point clearly we have drawn a simple sketch

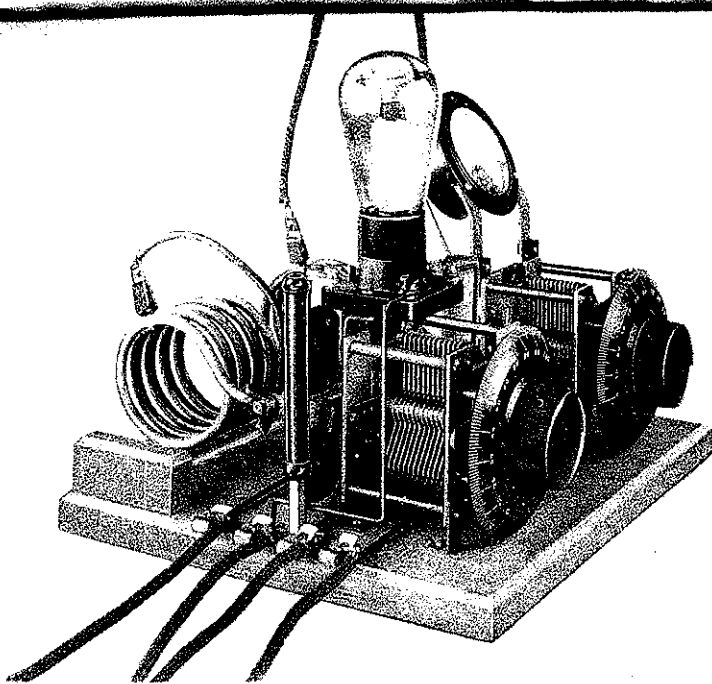


Figure 5

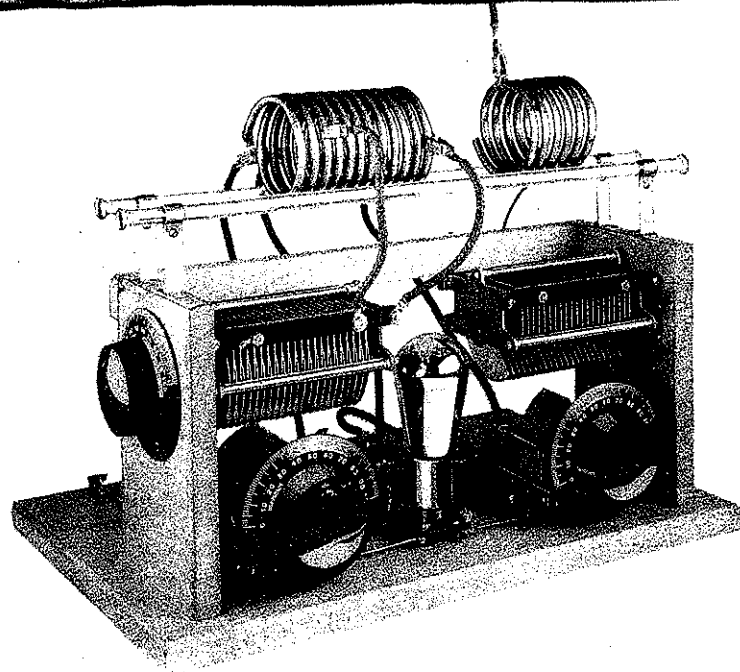


Figure 6

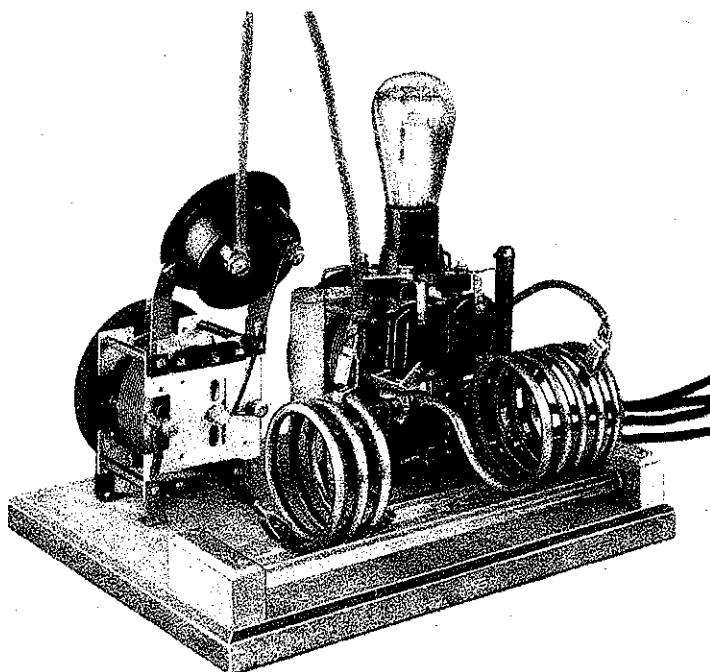


Figure 7

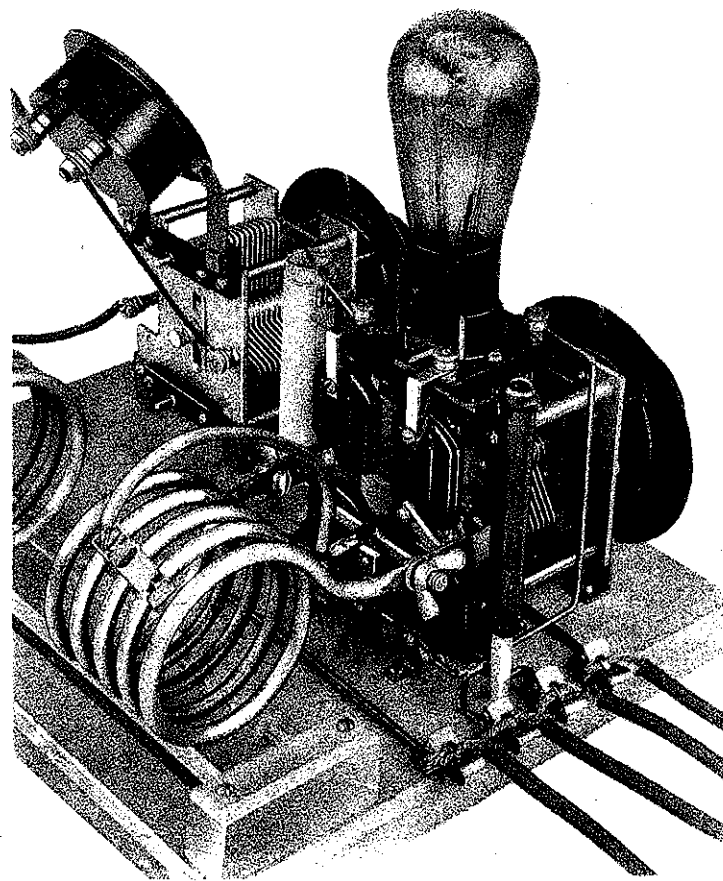


Figure 8

of an antenna of this type in Figure 9. If, for example an antenna is designed for transmission on a certain wavelength in the 50 meter band, then the total length of either the antenna or counterpoise taken separately would be approximately 40 ft. each, the individual lengths being indicated on the diagram by A and C.

Moreover, the third harmonic of an antenna may be utilized for transmission. Then, for transmission on the same wavelength in the 50 meter band, but utilizing a harmonic of the antenna, the antenna dimensions would require altering to give it a higher fundamental wavelength. The fundamental of the antenna required would have to be approximately 3×50 , or 150 meters. In the case of the longer fundamental, or 150 meters, the individual lengths of wire forming the antenna and counterpoise should be approximately 115 feet. Thus, we can realize that there is a very critical relation between the length of wire used and the fundamental wavelength of any antenna system.

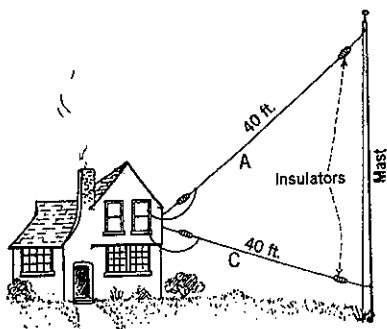


Figure 9

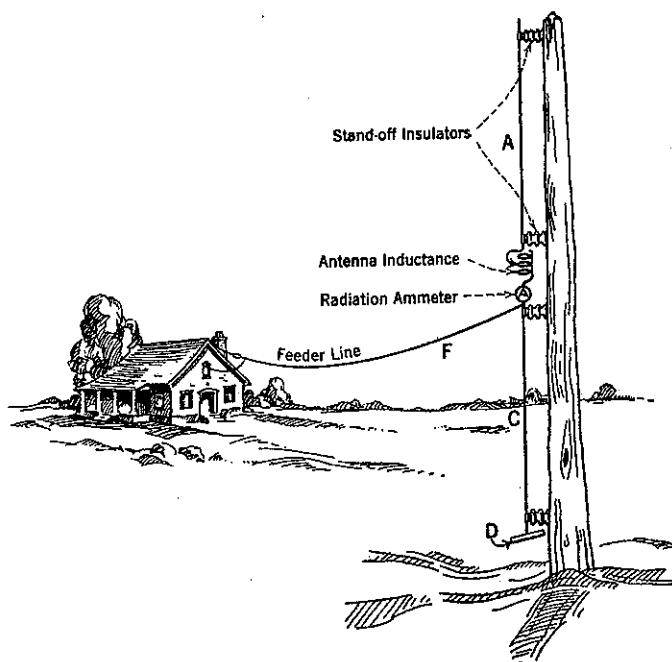


Figure 10

The tuning of the transmitting inductance is accomplished in the same manner as for a long wave circuit. In tuning, the procedure is to first calibrate the closed or primary circuit to the designated frequency, this adjustment to be followed by tuning the antenna circuit. This is done by moving a flexible clip along the antenna inductance until maximum reading is indicated on the radiation ammeter. Adjustment of the antenna or open circuit may also be made by means of a variable condenser inserted in series with the antenna, providing, of course, that a condenser is incorporated in this circuit. A close and critical adjustment of the antenna to any desired frequency is possible with the series condenser. It will be recalled that a series condenser lowers the wavelength of an antenna below that of its fundamental or natural wavelength. In brief, what we do in work of this kind is to tune the closed circuit in resonance with the antenna by selecting the best combinations of inductance and capacity. If it becomes necessary, the variable condenser

can be either short-circuited or otherwise eliminated from the antenna circuit.

Now the degree of coupling between the open and closed circuits is a very important matter. The best coupling distance between the primary and secondary inductances exists when the coupling is not too close to cause a broad signal to be radiated and make the circuit unstable in operation.

One of the simplest and most efficient antennas used with short wave apparatus is known as the "Hertz" type. A general idea of a short wave vertical Hertz antenna may be had from the sketch in Figure 10. You can see how the antenna inductance as well as the other circuit elements, such as the radiation ammeter, the antenna and counterpoise conductors marked A and C, are mounted on the wooden mast by stand-off insulators. The inductance mounted on the mast is connected electrically to the inductance in the transmitter itself (which is housed in the building) by the long single wire F which is called a feeder wire. An ultra-high frequency choke is often inserted in series with the feeder line for the purpose of suppressing harmonic radiation. This feed-line method of coupling an antenna to the transmitter itself is generally adopted in large transmitters because it permits the antenna to be situated some distance away in a free, open, unobstructed place. With this system the high-frequency oscillations produced in the oscillator circuit are carried through the feeder line to set the antenna into excitation.

Since there is no mutual inductance between the closed and open circuits with the feeder line method of coupling, the antenna circuit can be calibrated to its own frequency by variation of the antenna inductance until the maximum reading is observed on the radiation ammeter. Also, at the same time, the radio-frequency clip connecting the feeder line to the closed circuit inductance must be varied for a maximum output.

No direct ground connection is made to the lower section of counterpoise wire C, but, as shown in the drawing, the lowest point marked D is located several feet above the ground, this arrangement giving the effect of loading the circuit with additional capacity when necessary. The actual manner in which a short wave antenna is connected to a counterpoise must be determined by experimentation.

Conventional Type Short Wave Circuit. The master-oscillator power-amplifier circuit illustrated in Figure 11 will be used to describe a conventional type short wave transmitter. The theory of operation is as follows: The frequency of the generated oscillations is governed by the amounts of inductance used in L3 and L4 and the amount of capacity used in condenser C3. The oscillator circuit is coupled to the grid of the power amplifier through coupling condenser C, the actual connection being made with clip G1 attached to some location on the turns of the oscillator inductance L3. By sliding clip G2 along the grid coil L4 the feed-back of energy from the plate necessary for promoting the generation of oscillations can be easily regulated. Observe that milliammeter MA is connected in the circuit so that only the plate current of the oscillator tube will be indicated. The amplifier circuit is tuned by adjusting inductance L2 and variable condenser C2. The correct positions for all tuning adjustments for the particular tubes being used in the transmitter are determined by observing the radiation ammeter A for maximum indications.

When the fundamental wavelength of the antenna is the same as the designated operating wavelength then it will be found necessary only to tune the antenna with inductance L1. However, for a wavelength lower than the fundamental it will be necessary to insert a variable condenser C1 in series as we have suggested once before. This is done so that a decrease in inductance L1 will not be required below a point where efficient coupling between the open and closed circuits would be normally obtained.

The feed-back from the plate coil L3 to grid coil L4 is brought about by the changing magnetic field set up about L3 which acts upon the turns of L4. This method of transferring radio energy from one circuit to another is known as inductive coupling or magnetic coupling. A small radio-frequency choke coil, X, is inserted in the grid of the power-amplifier to suppress ultra-high frequencies. These parasitic currents are multiples of the fundamental or operating frequency and are usually set up whenever an oscillator tube circuit is coupled to a power-amplifier system. This choke also prevents any loss of high-frequency voltage and consequently the radio voltages generated in the transmitter are fully applied to the grid of the power-amplifier tube through the condenser C. The combination grid condenser C4 and grid leak R2 regulates the voltage of the oscillator grid. Condenser C acts as a blocking condenser to isolate the d-c. plate voltage from the grids of the tubes. A certain value of grid leak R1 is selected so that the correct operating potential of the power-amplifier grid will be maintained at all times.

Briefly, the function of the oscillator tube working into a circuit contain-

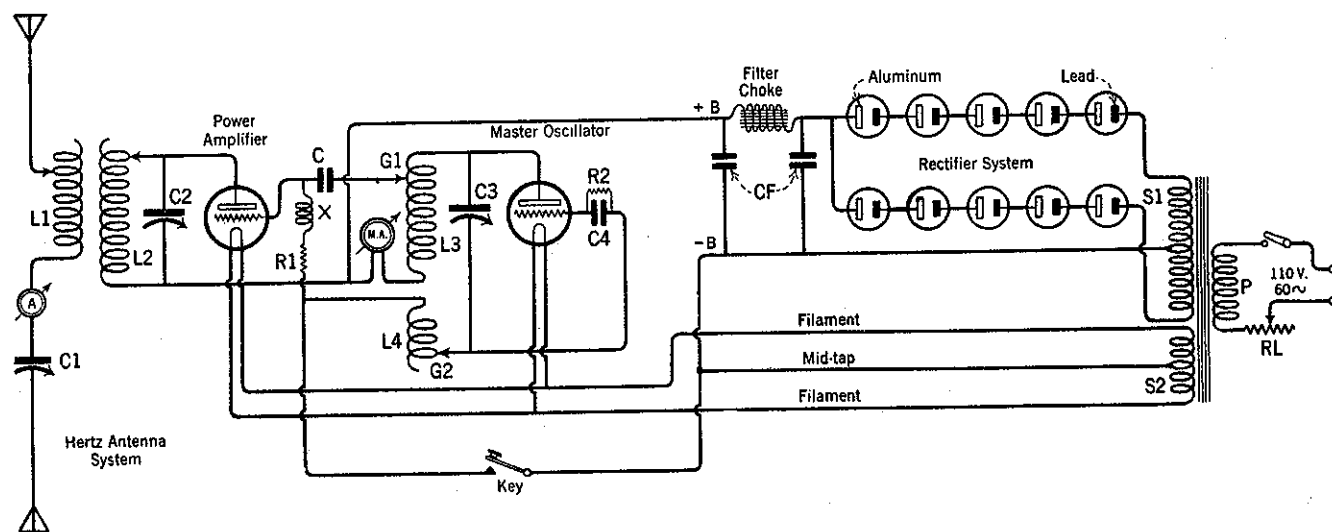


Figure 11

ing inductance and capacity is to generate radio oscillations of constant amplitude at the frequency allocated to the transmitter by the Radio Commission. These oscillations are transferred from the output of the oscillator circuit to the grid of the power-amplifier through condenser C. The strength of the signal is boosted up because of the amplifying properties of the power tube. Coils L1 and L2 constitute the antenna coupling transformer. A circuit arrangement of this kind permits a much greater power to be de-

livered to the antenna than could be otherwise obtained by coupling the oscillator tube directly to the antenna. Furthermore, this system gives stable operation and good frequency control of the antenna output.

Inspection of the diagram shows that there are three oscillatory circuits which must be tuned to the same frequency. They are (1) the oscillator tuned circuit L3, L4, C3, (2) the closed tuned circuit L2, C2, and (3) the antenna circuit L1, C1.

Because the losses occurring in a short wave transmitter are high, the adjustment of all of these circuits is very critical. The master-oscillator power-amplifier circuit will generate the steadiest signal, with the exception of one produced by a crystal-controlled transmitter. A circuit of this type is to be preferred where consistent communication is a requirement because antenna swinging has practically no effect on the frequency of the emitted signal.

One of several methods may be employed for keying the transmitter, such as breaking the grid circuit or changing the grid working voltage through an additional bias cut in by the key circuit. In the diagram, it is seen that the grid return circuits of both tubes are broken and the key inserted in series. When keying is accomplished by changing the grid biasing voltage from an operating voltage to a high blocking voltage, it is possible to key at high speeds.

Power to operate the tubes in the circuit just described is obtained from an electrolytic rectifier of the full-wave type. The rectifier supplies the requisite d-c. plate voltage from a 60-cycle, 110 volt a-c. source and operates as follows: The individual jars are assembled by immersing a strip of lead L and one of aluminum A, of equal size, in one pint of a saturated solution of borax and water. For each 75 volts output, one jar should be provided, and for each ampere supplied to the circuit, the approximate area of the aluminum should be 8 square inches. Current will flow through the jar in only one direction after the cells or jars have been "formed".

It may be advisable to list the precautions necessary when "forming" a jar. The output of the rectifying jars is short-circuited, and a-c. is passed through it for one to two hours. During the earlier stages of this process, there is a direct short-circuit placed on the transformer which requires that one or two lamps of suitable size be placed in series with the primary circuit to act as a load. If the transformer shows a tendency to overheat, lower-watt lamps should be substituted for the ones in use. The operation is considered complete when a dull white deposit appears on the aluminum plates and at this period the protective lamps are removed from the primary circuit. After making the usual circuit connections the rectifier will function to deliver a direct current of the proper voltage to the tube circuits.

The full-wave rectifier shown here is connected to a filter system consisting of a 30-henry choke coil and two large filter condensers marked on the diagram CF, CF, each having a capacity of 4.0 mfd.

We cannot over emphasize the importance of a good filter system because considerable interference may be caused by a C.W. transmitter if its 60-cycle, or motor-generator commutator frequency, is permitted to modulate the output.

The secondary winding S1 delivers the alternating current to be rectified through the jars and, due to their one-way conductivity of current flow, a direct current is obtained from their output which in turn is supplied to the plate circuits. The filaments are heated with alternating current furnished by the filament winding S2 of the power transformer. The grid return lead in common with both tubes is connected to the center tap of this winding with the transmitting key inserted in series. The power furnished to the primary from the main a-c. supply is regulated through the line rheostat R1, this circuit being closed and opened through the main line switch SW.

Hertz Antenna. The various short wave transmitting antennas in common use employ what is known as the "Hertz Antenna". It is interesting to know that the Hertz antenna does not use any ground connection, and that it was the earliest type ever constructed for the express purpose of radio wave propagation. In later years Marconi conceived the idea of actually connecting the antenna to the earth.

A Hertz antenna may be set up either in vertical form, horizontal, or bent so that portions of it occupy both positions. Experiments have proven that in this type of antenna the distribution of current and voltage are non-uniform, this being due to the fact that there is always a high radio-frequency voltage at the upper or antenna end, as well as at the lower or counterpoise end. At the electrical center of the antenna, the current is highest when operating at the fundamental of the radiating system. If you were to test along the antenna circuit from point to point toward either end, beginning at the middle, less current and more voltage would be evidenced as the extreme far ends were approached. A test such as we suggest here for determining the distribution of voltage can be performed easily by the use of a neon tube. This device consists of a glass tube containing a small quantity of the rare gas "neon". The principle upon which this testing device functions is that when the gas is acted upon by high-frequency waves in space, (the radiations coming from any active antenna or electrical conductor acting in like manner), the gas is ionized. This breaking up of the gas atoms produces a beautiful purplish luminescence, called a glow. The tube is often called a glow tube. It is used in a practical way in automotive electrical work for checking up on imperfect operating high tension circuits connecting to the spark plugs. If the neon tube is held close to the high tension leads, and the circuit functions normally, electric waves will radiate from the wire and cause the tube to glow.

In testing an active Hertz antenna, by moving the tube along the conductors, points will be found where the tube glows brightest; these locations are the points where the highest voltages are generated. A few trials will soon tell you how far the tube must be held away from any live high-voltage wire conducting a-c. to obtain a satisfactory indication.

It is to be understood that tests of this kind can be made by utilizing meters instead of the glow tube. Our reason for discussing this voltage and current distribution is based upon the fact that there are two methods for energizing an antenna of this type. These methods are known respectively as the "voltage feed system" and the "current feed system".

The voltage feed system employs but one wire, carrying a low current but a comparatively high voltage. A single feeder wire connects the transmitter circuit to the antenna as shown in Figure 12. When making adjustments to this circuit the feed wire should be connected to a point on the antenna where a current node exists, as for instance at point marked X.

The current feed system, on the other hand, employs two wires as illustrated in the elementary diagram in Figure 13. A large current at low voltage flows to the antenna from the output of the transformer which in turn receives its excitation from the transmitter. This system is used in many installations for exciting the antenna. It is used especially in high power broadcasting stations of 50 Kw. or more. In high power work the two wires are strung on wooden poles leading to a large transformer installed in a weather proof shed, and from this point the connecting leads are run to the antenna proper. This special construction permits the antenna system to be located in an unobstructed area at some remote distance from the transmitter.

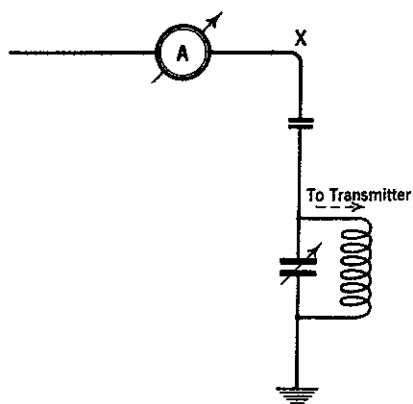


Figure 12

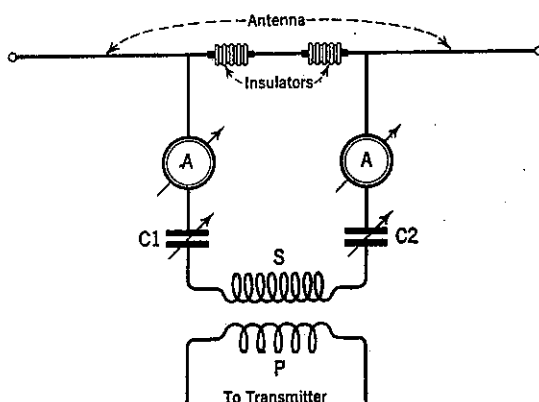


Figure 13

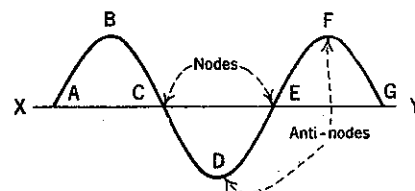


Figure 14

The transfer of radio power from the closed to the open circuit is through the transformer referred to in the paragraph preceding. This provides inductive coupling, which is the method most familiar to us, in the ordinary coupling of high-frequency circuits. In Figure 13 notice that the transformer secondary is connected directly to the center of the antenna. An antenna which radiates several harmonics along with the fundamental frequency will have several nodal points (zero current points) distributed along its length. The indication at the nodal point of the fundamental or first harmonic is pronounced as would be evidenced by the brightness of the neon tube when used in a test. However, it would be noticed the nodal points of the second and high harmonics are located at different points along the antenna and furthermore the nodal point of each harmonic would become less pronounced as their frequency increased to higher orders, this phenomenon being visualized by the relative intensities of the glow of the neon tube. That is to say, the power or energy possessed by the fourth harmonic is less than that of the third, and the energy in the third is less than that of the second, and so on. This rule cannot always be followed for there are isolated instances where the greatest power is not to be found in the fundamental, also called the first harmonic.

To make clear exactly what we mean by a nodal point we have drawn the curve in Figure 14. In this curve the line XY is the zero axis on which an alternating current sine wave is represented. The sine wave shows that the points of zero current (or voltage) marked A, C, E and G are called nodes. Whereas, the points of maximum amplitudes marked B, D and F are the anti-nodes or loops.

Condensers C1 and C2 are sometimes inserted in series with each wire of a two-wire feed line in the manner shown in Figure 13. This is done in order that both wires may have equal field strength to equalize the effect of the magnetic field and reduce any radiation troubles. Also, a radiation ammeter may be supplied in either side of the antenna (or one in each side as shown in the drawing) and the meters will read alike if placed in the exact electrical center of the radiating system. A person without experience in short wave transmission is apt to be unsuccessful in the attempt to satisfactorily adjust a voltage feed (or single wire) Hertz antenna.

The peculiar properties exhibited by short waves and their persistence in covering long distances on low power has encouraged engineers to conduct exhaustive tests in this direction; they expect soon to be able to utilize the very short waves, as low as 5 meters or less, which involve the highest frequencies. Commercial short wave sets operate successfully down to about 16 meters.

Let us compare a 5 meter and a 4 meter wave. A 5 meter wave represents a frequency of approximately 60,000,000 cycles. Expressed in sub-multiples of the unit "cycle" this wavelength is 60,000 kilocycles, or 60 megacycles. Now, a 4 meter wave has a frequency of approximately 75,000,000 cycles or 75,000 kilocycles, or 75 megacycles. Working out a simple problem in subtraction will tell you that while there is a difference of only one meter in wavelength between the two waves yet the frequency difference between them is 15,000,000 cycles. It is easy to figure out how a great number of stations could operate within this one meter band, or its equivalent 15,000,000 cycles, if the use of the very short waves could be made a practicability.

Short Wave Transmitting Tube. The UX-852 short wave tube is particularly suited for use as an oscillator or power amplifier in circuits designed for short wave transmission, especially at wavelengths under 100 meters because of the tubes low internal capacity. Laboratory tests show that the grid to plate capacity is practically negligible, it being computed at 0.14 micromicrofarads. The tube has a power rating of 75 watts. A high electron emission is possible because of the XL filament used. It will oscillate with stability on 20 meters and under certain conditions at $7/8$ of a meter. With a slight reduction in output or rated plate voltage the tube may be operated as a crystal controlled oscillator. The limitations of the crystal make power reduction necessary.

Damaging base flashes are prevented by the double end or T-shaped construction of the glass envelope. The photograph, Figure 14, Lesson 60, clearly shows that each pair of electrodes are provided with two parallel leads for high current carrying capacity. It is imperative that pairs of leads be used always when making connections between the tube and the transmitter circuits. Alternating current should be supplied to the filament when possible. The

plate and grid return leads should be connected to the electrical center (center tap) of the filament heating winding on the power transformer.

Inasmuch as it is quite impractical to measure the output of the tube at short wavelengths, its correct operation may be judged with sufficient accuracy by observing the plate. During calibration the plate temperature should not be permitted to rise above a value which will cause it to heat to more than a cherry redness. A plate which is heated to this characteristic color is taken to be equivalent to dissipating approximately 100 watts, caused by the electron bombardment of the anode (plate).

Inductive or Magnetic Coupling. The Government regulations require the use of inductively coupled antenna circuits for the transmission of radio waves. One of the advantages of magnetic coupling is that it permits the use of loose coupling which sharpens or peaks the wave, thus decreasing interference with neighboring receiving sets. A sharp wave reduces losses because it concentrates more of the energy on the designated wavelength. One advantage of this type of coupling is the elimination of a series condenser, except in extreme cases when working on a wavelength below that of the fundamental of the antenna. Other advantages are: Harmonics of the oscillator can be suppressed more efficiently, and the so-called "Key thump" can be reduced considerably. Also, a change from one wavelength to another may be made more conveniently without the necessity of locating the nodal point either at the filament connection or the grounded point. It may bear repeating that the nodal point is the center of a radiative oscillating system, such as an antenna, where the current is maximum and the radio-frequency voltage is zero.

Crystal Controlled Transmitter. We mentioned in the early part of our lesson that many short wave transmitters operated either for broadcasting or commercial telegraphic communication, or both, obtain their stations frequency by the use of a small quartz crystal. It is now firmly established that a quartz crystal will maintain stabilized frequency for a transmitter within very close limits. The Radio Commission at Washington has drawn up regulations which require that a station shall not waver from its assigned frequency by more than 500 cycles. To hold a circuit which is oscillating at a frequency of about, let us say, 3,000,000 cycles, to within a band not extending more than 500 cycles either side of this value is a matter which demands great engineering skill. It is obvious that in a case of this kind the percentage of efficiency required is unusually high.

Antenna swinging has practically no effect upon the steadiness of a signal in a crystal controlled transmitter, this being an essential feature when consistent communication must be carried on. An elementary diagram of a crystal controlled oscillator is given in Figure 15. The purpose of this circuit merely is to provide the designated frequency of the transmitter and the output of an amplifier which in turn feeds its power to the antenna.

Certain classes of high-power stations employ a 7.5 watt tube in the crystal controlled oscillator circuit as shown in Figure 16. This tube's output is made to feed into a first-stage amplifier consisting of a 50 watt tube. The latter tube in turn delivers its output energy to either a 250 watt or 1 kilowatt tube, and again, following this stage we may possibly find a final ampli-

fier circuit containing one or more 20 kilowatt tubes. Thus a large radio power at a constant frequency is delivered to the antenna in this manner. The whole process is simply one of building up the power of a particular frequency through successive stages of amplification leading to the antenna.

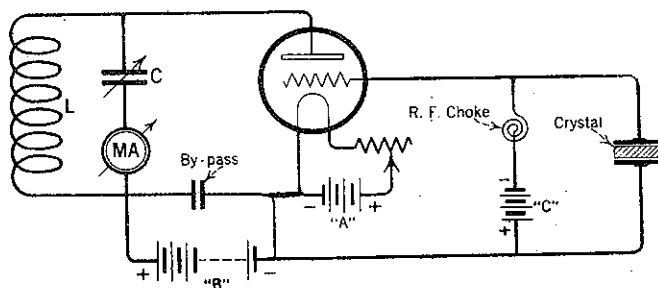


Figure 15

Now examine the circuit in Figure 15 which shows a typical crystal controlled oscillator. It is seen that the circuit consists of the crystal itself, a radio-frequency choke coil, a source of grid biasing voltage, the grid or input circuit of a 7.5 watt tube and the usual "A", "B" and "C" batteries.

Operation of the Circuit. The circuit in Figure 16 is purely schematic and is only intended to set forth the principles of coupling a master control oscillator to a series of stages of power amplification. Any one of several methods of coupling may be advantageously used between the various tubes, as for example, transformer coupling (this being the method employed in the circuit illustrated), impedance, or resistance coupling.

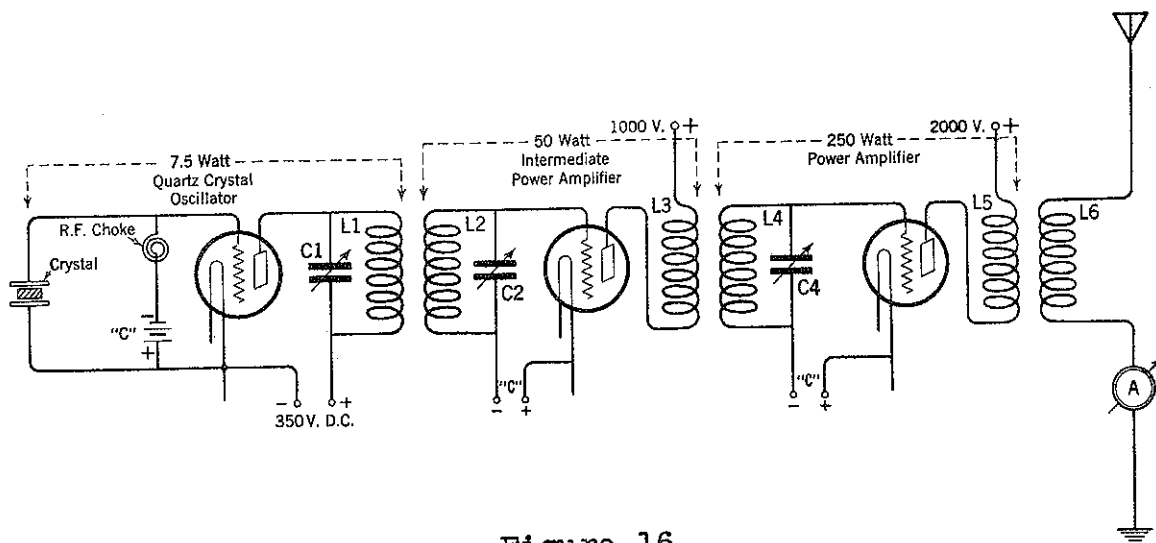


Figure 16

Notice that the inductance inserted in the plate circuit of the oscillator tube is shunted by a variable condenser which permits the circuit to be quickly tuned to any desired frequency within the limits of the transmitter. When the set is in operation the selected frequency is transferred from inductance L1 to L2 by electromagnetic induction. The alternating e.m.f. set

up in the circuit of L2 is applied to the grid of the first stage amplifier and the influence of this charged grid upon the electron stream in the tube causes the same frequency to be repeated in varying plate current passing through L3. Again the selected frequency is communicated to a second stage of amplification, this time through the action occurring between L3 to L4. The induced voltages in L4, when impressed upon the second amplifier grid, causes the plate current in this tube's output to vary at the designated frequency through L5. Now if a further increase in power is not desired then L5 may be loosely coupled (inductively) to the antenna through L6.

Remember that the gain in radio power for any individual stage of amplification depends upon the characteristics of the particular tube used and the power supplied. The plate and filament voltages supplied to the various tubes is determined by their size and rating. Charts giving complete specifications of vacuum tubes will be found in one of your previous lessons. Let us mention once more that a 7.5 watt tube worked as an oscillator is normally supplied with a plate potential of about 350 volts, a 50-watt tube working as an amplifier with 1000 volts, and a 250-watt tube with 2000 volts.

It should now be easy to understand how a crystal oscillator associated with a vacuum tube can feed its output to a more powerful tube which, in turn, is coupled to the antenna, or else the crystal oscillator and first amplifier may be coupled directly to the antenna without any intermediate stage or stages of amplification.

Power also may be derived from a generator or from batteries. In low power sets a bank of heavy-duty "B" batteries will give very efficient service over long periods. A storage "A" battery may be used for supplying the filament terminal e.m.f.

Rectifiers of the thermionic type, (hot filament type) are often used for the power supply unit. A small filter consisting of chokes and condensers is then installed to smooth out the ripples in the rectified pulsations. A device of this kind can be designed to deliver sufficient direct current plate power as well as alternating current filament power from a special winding on the transformer for use with low power tubes of the UX-210 variety. This combination makes a very convenient source of e.m.f. for it is necessary only to plug the cord attached to the power transformer into the outlet of the 110 volt a-c. supply line.

Quartz Crystal Controlled Oscillator. One of the greatest scientific developments of recent years founded on the oscillating properties of a quartz crystal, has found a practical application in the frequency control of radio transmitters. A crystal can be utilized to control any r.f. system with reasonable output power. Although numerous circuit arrangements have been devised by which a crystal's output frequency may be made to ultimately set up oscillations of similar frequency in the antenna, yet after studying these circuits carefully we will find them quite alike fundamentally. Either the crystal-master oscillator circuit is coupled to a main power amplifier, with the latter circuit working into the antenna, or the transmitter may employ several intermediate stages of amplification between the crystal-oscillator and the main power amplifier. In every instance, though, the function of the

amplifying stages is merely to build up the radio power progressively at the frequency dictated by the crystal's natural oscillation period.

When an electric circuit is formed by a conductor connecting two metal plates between which a crystal is placed, and the plates are then subjected to alternating mechanical impulses, the crystal generates corresponding alternating currents. This effect by which a mechanical stress imposed upon natural minerals of this kind is capable of setting up a flow of electrical current was first discovered by P. and J. Curie, famed for their research work with Radium. Moreover, it was found that the opposite effect could also be produced by the crystal; that is, when an electrical pressure (e.m.f.) of an alternating nature is impressed between the plates, it will cause a similar mechanical vibration in the crystal. It is evident then that a quartz crystal can be used for converting mechanical vibrations into electrical oscillations and vice versa. We are forced to realize that nature is indeed a wonderful master over the materials and forces on our universe when we stop and think that in recent experiments scientists have been able to convert electrical current into sound waves solely with the aid of certain kinds of crystals. This phenomenon is apparent even though the plates or metal conducting sheets do not quite touch the respective faces of the crystal.

This peculiar property which a crystal exhibits has been given the name "piezoelectric". Different kinds of crystals have piezoelectric properties, but they are not all suited mechanically for practical uses and, furthermore, they do not all have the same pronounced electrical properties as does the quartz crystal. Each piezoelectric crystal has a natural mechanical vibration peculiar to itself and the effects are strongest when an electrical oscillation is adjusted closely to the natural mechanical period of the crystal.

Recent laboratory experiments tend to bear out the fact that when a crystal is electrically charged it undergoes a succession of mechanical vibrations, or as some would say a "tremulous motion". Its shape is distorted in this action and as quickly as possible the crystal seeks to resume its original physical shape, as when undisturbed, or in a state of rest. It is while endeavoring to get back to normalcy, that is, to a normal condition of rest, that we say the crystal is "oscillating". The mechanical vibration occurs at a tremendously fast rate, in the order of the radio-frequencies. The oscillations set up in the electric circuit will reach maximum amplitudes when the frequency of the tuned circuit, consisting of inductance and capacity, is set close to the natural frequency of the crystal.

Thus, it is possible to connect an electron tube oscillatory circuit to a quartz crystal and control the frequency of the current circulating through the system. One method of connecting a piezoelectric oscillator (quartz crystal) to an oscillating tube circuit is shown in the diagram in Figure 15. It is to be understood that the crystal can be inserted either between the grid and plate or between the grid and filament. If the crystal is inserted between the grid and plate, the capacity of the filament to grid electrodes will be sufficient to provide the requisite feed-back path for oscillations. However, when the crystal is placed between the filament and grid, the

capacity of the grid to plate electrodes provides the path through which energy is fed back from the plate circuit to the grid circuit. You know from your previous studies about oscillator circuits that the reintroduction of voltage to the grid from the plate circuit maintains the tube and its associated circuits in a state capable of generating continuous oscillations.

The following is a brief account of the reasons generally advanced in scientific circles for the action of the crystal when working in conjunction with the vacuum tube oscillator. Refer to the diagram in Figure 15. The circuit is placed in operation by adjustment of the filament voltage until a normal condition is reached, or we could otherwise say, until normal plate current flows. While the plate current builds up during the initial starting of the circuit it passes through inductance L , since L is connected in series. It is obvious that the plate current undergoes a rise through L . Undoubtedly there also occurs a momentary rush of energy toward the crystal, and although conduction current cannot pass through the crystal because of its high insulating properties this rush or surge, nevertheless, places an electric charge upon the surfaces of the crystal. The electric charge in turn causes the crystal to vibrate mechanically. A vibration or oscillation once started will continue because the plate inductance L is connected by a variable condenser and the circuit is otherwise arranged to become regenerative by the familiar method which utilizes the self-capacity of the tube elements for the purposes of feed-back as just mentioned. There must be, of course, the proper relation between the crystal's own natural frequency of vibration and the frequency or rate at which the first surge of energy changes in value in order to excite the crystal and cause it to move to its greatest limits.

Now let us summarize the action occurring in the circuit in Figure 15. The production of a high-frequency current by this system is thought to be due to the following combined effects: (1) to the ordinary change of current when the circuit is placed in operation; (2) because of the tremulous or mechanical vibrating action of the crystal; and (3) by reason of the feed-back between the tube elements, sustained oscillations are generated.

In order to start a quartz crystal oscillating it may be necessary to vary the capacity of condenser C very slowly. The necessity for this preliminary adjustment may be accounted for by the use of an incorrect value of inductance, or perhaps the crystal itself lacks the necessary freedom to move.

A radio-frequency choke coil is inserted in the grid return lead to eliminate that part of the radio-frequency voltage loss that is due to the direct flow of current through the grid circuit. The grid is biased with a "C" battery to keep the swing of the crystal controlling voltage over on the negative side of the grid-voltage-plate current characteristic. A maximum output will be obtained from the circuit when a minimum of grid current flows. When a negligible grid current flows, it means that the grid is not blocked by a heavy negative charge that would act to reduce the plate current to zero, which is an undesirable condition. A small amount of plate current is necessary before a crystal circuit will start oscillating.

About Crystals and Crystal Holders. It is necessary to subject a crystal to a change of some kind in order to start it oscillating. This may be done in

The several natural mechanical vibrations which are always present are thought to be due to a disarrangement of the molecules of the crystal. Any ordinary vacuum tube oscillator also generates a series of harmonics which are due principally to distortion produced by the tube circuit. It frequently happens that a crystal will not oscillate even when the faces appear to be parallel. A little grinding in a mixture of No. 301 powdered emery and kerosene will often bring back oscillations. This is done by pushing the crystal in a circular to and fro motion on a flat surface holding the grinding compound. This process, known as "lapping", should be finished off by grinding in a mixture of No. 100 carborundum and oil, after which the crystal should be cleaned with carbon tetrachloride (pyrene liquid or Carbona). Fingerprints, dirt, or grease will cause the crystal to become inoperative. In this case it must be washed in the grease solvent. The grinding of a crystal requires great skill and should not be undertaken by one unacquainted with the work.

All of these interesting facts indicate the extreme sensitivity and peculiarities of the quartz crystal. Crystals are rapidly becoming standard equipment in both short and long wave vacuum tube transmitters. As can be seen by the schematic diagrams the circuits in themselves are simple, and experience proves that their operation is stable under the severe conditions met in radio communication.

Amplifying Harmonics of a Crystal for Short Wave Work. When the plate tuned circuit of a crystal oscillator tube is tuned slightly off resonance with the natural period of the crystal, the circuit generates several strong harmonics which are multiples of the fundamental. When it is desired to pick off a particular harmonic for exciting the grid of the power-amplifier tube, it is necessary only to adjust the grid-tuned circuit of the amplifier L2 C2, Figure 16, to the same frequency as the harmonic.

A crystal which is not too thin is desirable for average operating conditions because it is less likely to break down and crack than very thin ones. The best arrangement is to employ a thicker crystal which has necessarily a higher natural period. For instance, the master control circuit in Figure 16 may employ a 160-meter crystal. In this case the second harmonic is 80 meters, and the third harmonic 40 meters. When it is desired to send on the 80-meter wavelength, the power amplifier grid circuit L2 C2 is tuned to 80 meters. On the other hand, if it is desired to send on 40 meters, the L2 C2 circuit should then be tuned to this harmonic. From this arrangement it is seen that the power-amplifier becomes a frequency changing device. In the case of the second harmonic, twice the input frequency is obtained from the output of the master oscillator.

Let us assume that the grid-tuned circuit L2 C2 is adjusted to receive a maximum input from the second harmonic, 80 meters, produced by circuit L1 C1. The output of the first power-amplifier tube is then resonated to 80 meters; in turn, the input circuit L4 C4 is tuned to resonance to 80 meters, and lastly, the antenna system is calibrated to operate on 80 meters.

The crystal-controlled circuit is very flexible and it is possible to operate with a crystal having a 160-meter natural period on any of its harmonics as we have just explained. The individual circuits may be shielded to prevent

the magnetic field of the coils from spreading out and inducing radio-frequency current in the component parts of the circuit. When shielding is employed, it is important that the coils be made small in order to prevent losses due to absorption by the shielding.

A summation of the foregoing facts relating to crystal-controlled oscillators indicates that the crystal dictates the frequency of the oscillations and the vacuum tube simply furnishes the power to drive the crystal. Crystals can be ground to give as high as 10,000,000 cycles (10 megacycles), or as low as approximately 25,000 per second, but it is much simpler to employ a crystal having a frequency of about 2,000,000 cycles (2 megacycles) and operate the amplifier circuits at one of the various individual harmonics.

It may be worthy to mention that the fundamental frequency of the crystal is called "harmonic No. 1". Harmonic No. 2 is exactly twice the frequency of the fundamental. Harmonic No. 3 is exactly three times the frequency of the fundamental, and so on. In the case cited above, the amplifier circuit may be operated on the fifth harmonic, 10,000,000 cycles (30 meters), the fundamental of the crystal oscillator being 2,000,000 cycles (150 meters). Should it be desired to transmit on 30 meters or 10,000,000 cycles, a crystal having a fundamental of 2,000,000 cycles (150 meters) can be employed.

It is possible, under ordinary conditions, to find a dozen or more harmonic frequencies having sufficient power for practical application. It must be remembered, however, that the fundamental is usually the more powerful as we have suggested once before and, in progressive order, the other harmonics become less powerful.

Neutralizing. When a crystal oscillator circuit is operated at the fundamental of the crystal, it is then necessary to neutralize the power-amplifier tube. This means that the grid to plate capacity within the tube must be so balanced out, giving the effect that it does not exist at all. This small capacity, if present, encourages the setting up of unwanted oscillations in the circuits resulting in erratic operation. These oscillations are better known as "self-oscillations". Inter-electrode capacity can be cancelled or balanced out by connecting the grid of the amplifier, through a variable condenser, to some portion of the plate inductance. The correct neutralizing voltage is obtained from the potential drop across the inductance when current flows. To actually eliminate the tube's capacity effect the neutralizing voltage must be equal to and opposite to the voltage resulting from the feed-back between the grid and plate electrodes. When one of the crystal's harmonics is utilized for the station's assigned frequency then such a conventional neutralizing circuit is not quite so necessary, and in many cases not at all.

EXAMINATION - LESSON 63

1. (a) What are a ground wave and a sky wave? (b) What is skip-distance?
(c) Tell briefly how the above phenomena are accounted for?
2. Draw a schematic diagram of a shunt-feed Hartley type short wave transmitter. Now mark each circuit element with a distinguishing letter and in a neat column list these marks with the corresponding names of the parts in the diagram.
3. Draw a simple transmitter diagram of a series-feed Hartley oscillator.
4. How may either one of the circuits you have drawn in answer to Questions 2 and 3 be keyed in order to carry on telegraphic communication?
5. (a) What two methods are employed for the frequency control of a transmitter's output in modern vacuum tube equipment? (b) What is the limit set down to which a transmitter can swing off its assigned frequency?
6. (a) What does the term "piezoelectric" refer to? (b) Give several precautions that are necessary in the use of a crystal, in regard to its mounting, care and operation in the circuit. (c) Is it possible to use a frequency other than the fundamental frequency of a crystal-oscillator circuit? (d) State reason for your answer to question (6c).
7. Draw a schematic diagram of a crystal-controlled oscillator.
8. (a) In what way is a Hertz antenna different from the Marconi type antenna? (b) Name two coupling methods used for carrying radio power from a transmitter to an antenna system which may be located in an unobstructed area some remote distance from the transmitter itself.
(c) Draw two simple schematic diagrams showing the general arrangement of the two types of coupling named in answer to question (8b). above.
9. Name four advantages offered by the use of inductive coupling between the output of a transmitter and an antenna.
10. Draw a simple diagram of a crystal-controlled oscillator coupled to one stage of amplification with the latter delivering its power to the antenna.